Generation and Control of Artificial Large-Scale Ionospheric Turbulence

Contract F61708-96-W0322.

Project–Coordinator: Keith Groves

— Final Report —

1. INTRODUCTION

The commencement date of the project was October, 1995. The following represents the Final Report, covering the period September 1997 to March 1999.

2. RESEARCH

2.1 Scientific Objectives

The main scientific objective of the project is the experimental investigation of plasma turbulence formation by the action of a powerful pump wave and the subsequent generation of artificial large-scale ionospheric turbulence (ALST) by interaction of high and low frequency turbulence, with special emphasis on control of its features. We have studied the following:
1) The generation and decay mechanisms of ALST;
2) The relationship between ALST and artificial small-scale ($l_\perp \leq 100$ m) turbulence;
3) New methods of diagnostics of coherent structures in ALST.

2.2 Research Activities

Two experimental campaigns with the SURA ionospheric modification facility at Vasilsursk, Russia, have been carried out in the years 1997 – 1998 (in October 1997 and August 1998), devoted to the objective of the present project. The experimental and theoretical work has proceeded according to plan.

2.3 Scientific Results.

The main scientific results obtained from the experimental campaigns and the theoretical work are summarized below.

2.3.1 Features of ALST

- It has been found that the strong artificial large-scale irregularities (ALSI) can be excited even for underdense heating if the plasma frequency at upper hybrid resonance height, f_{uh} ($f_{uh} = \sqrt{f_0^2 - f_{ce}^2}$, is lower than the F_2-layer critical frequency and shown that small-scale irregularities (striations) are of great importance for generation of such irregularities. For fully underdense heating (when $f_{uh} > f_{0F_2}$) under quite ionospheric conditions it has not been found any modification in the day ionosphere whereas the generation of a noticeable

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13. ABSTRACT (Maximum 200 words)

This report results from a contract tasking Radiophysical Research Institute (NTRFI) as follows: The contractor will investigate generation and control of artificial large-scale ionospheric turbulence. He shall perform three primary tasks as described in his proposal 1) seek to understand the generation and decay mechanisms of artificial large-scale turbulence (ALST) in the ionosphere; (2) study the relationship between ALST and artificial small-scale turbulence (ASST); and (3) investigate new methods of diagnostics of coherent structures in ALST.

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ALSI occurs in the night ionosphere. It is clear that the striations are immaterial in a mechanism of generation of these irregularities.

- Two mechanisms of the strong ALSI generation have been resolved basing on experimental data. One of them leads to growth of irregularities in a wide scale range $l_\perp \geq 200$ m. According to the previous investigations the ALSI with $l_\perp \simeq 300-600$ m are produced in a vicinity of the pump wave reflection level due to thermal self-focusing instability development. It is most likely that larger irregularities with $l_\perp \geq 1$ km are a result of amplification of natural irregularities due to ionospheric plasma heating. The second mechanism has a higher threshold than the first one and it is responsible for excitation of irregularities in a rather narrow scale range $l_\perp \simeq 50-200$ m. It is most probably that these irregularities are produced due to a large-scale nonlinear structuring in a modified ionospheric F-region [*Gurevich et al., Phys. Lett. A, 239*, 385, 1998] in which the striations play a crucial role. It is a reason why these irregularities are not effectively generated when a pump frequency is close to a gyroharmonic frequency and the striations are strong suppressed.

- It has been performed the first investigations of ALSI features when a square intensity modulation of the pump is used and found that the pulsing heating leads to stronger suppression of $50-200$-m scale irregularities than kilometer-scale ones. It is also an additional evidence of existence of two mechanisms for the ALSI generation. Performed measurements have shown some opportunities to control over ALSI spectral characteristics employing complex timing for pump wave operation. However, new measurements are needed before we can establish key parameters determining such a control.

- It is shown that combined employment of the satellite, SEE, and X-mode AA measurements allows to investigate AIT temporal evolution in a wide scale range from a few meters to a few kilometers. From satellite observations it has been found that the ALSI with $l_\perp \simeq 50-100$ m have the typical development time $\tau_1 \simeq 15-30$ c and the typical relaxation time $\tau_2 \simeq 15-20$ c; for irregularities with $l_\perp \simeq 0.6-1.2$ km the typical development time $\tau_1 \simeq 40-90$ c, and the typical relaxation time $\tau_2 \simeq 120-240$ c. From the anomalous attenuation measurements for X-mode probing waves we can conclude that the ALSI with $l_\perp \simeq 100-200$ m have the typical development time $\tau_1 \simeq 20-30$ c, and the typical relaxation time $\tau_2 \simeq 20-30$ c. Lastly, from SEE measurements it follows that the typical development time for the DM is $\sim 3-5$ c, which corresponds to growth time for $3-5$-m scale striations. The dependence of τ_1 on $l_\perp$ can be represented in a power-law form: $\tau_1 \propto l_\perp^\alpha$ with the power index $\alpha \simeq 0.5$. A dependence of τ_2 on $l_\perp$ in a scale range from $\sim 50-100$ m to ~ 1 km can be also represented in a power-law form: $\tau_2 \propto l_\perp^\beta$ with the power index $\beta \simeq 0.9$. The results concerning temporal evolution of the ALSI are in good agreement with earlier performed experiments.

2.3.2 An artificial "hole" produced in the ionosphere by HF powerful radio waves

On October 24, 1997 since 16:00 till 19:30 LT in the ionospheric modification experiments at the Sura facility using spatially splitted heating, a significant drop (by $20-40\%$) of the F-region electron density was obtained twice. In the measurements two Sura transmitters operated at frequency $f_1 = 4785$ kHz with a split antenna pattern: pump power was divided between two beams inclined $\pm8°$ from zenith in the E – W direction. The third transmitter radiated the pump wave to zenith at $f_2 = 5750$ kHz. The ionospheric density profile was monitored by an ionosond placed alongside the Sura facility. Besides, multi-frequency Doppler sounding of the disturbed volume by means of 7 probing waves was also used. The results obtained have shown a possibility of artificial producing

of very strong large-scale electron density inhomogeneity employing the scheme of spatially splitted antenna pattern heating.

2.3.3 Study of artificial ionospheric disturbances using oblique chirp-sounding technique

Employing the wideband chirp-sounding technique with high frequency resolution allows to reveal important peculiarities of large-scale irregular structures generated during ionosphere heating. Experiment was carried out on October 21-25, 1997 at the Yoshkar-Ola – Sura – N.Novgorod path. The ionosphere was disturbed by means of the Sura heating facility located 35 km to the south from the middle point of the sounding path. The Sura facility operated since 14.30 till 18.30 LT. The chirp-sounder radiated in a frequency range from 2.7 to 11.7 MHz, the sweep frequency rate was 149 kHz/s. Ionograms were registered every two minutes.

During the heater on period the following effects were observed:

- It is observed development of spread of O- and X- components for 1F2 propagation mode in a wide frequency band from LOF to MOF with typical growth and decay times $\sim 1 - 2$ min. The critical frequencies for O- and X- magnetoionic components increase by about of 300 and 400 kHz, respectively.

- It is observed development of spread of O- and X- components for 2F2 propagation mode. The value of the effect and its occurrence increase when the Sura facility operates using a scheme of antenna pattern splitting.

- Within $\sim 5 - 6$ min after the pump wave switch on it is observed weakening of intensity for 2F2 propagation mode up to its disappearance on ionograms; after heater switch off it restores with relaxation time of $\sim 4 - 5$ min. The effect is more pronounced for a wide heating antenna beam and for the long-time pumping under the "could start" condition.

The decrease and disappearance 2F2 propagation mode during the ionosphere modification can be associated with large-scale gradient ionization like TIDs forming tilts in the ionosphere which lead to essential distortion of the ionograms.

2.3.4 Features of artificial low-frequency quasi-periodic amplitude oscillations (QPAO) of X-mode probing waves reflected from the ionosphere

It has been performed new more detailed investigations of artificial low-frequency quasi-periodic amplitude oscillations (QPAO) of X-mode probing waves reflected from the ionosphere. Summing up our experimental findings, we may shortly formulate the following QPAO empirical model:

- The QPAO begin being detected within $\sim 0.07 - 1$ s after the pump switch on depending on day time, pump power, f_x, and relation between f_0 and f_{0F_2}. It has been found that their generation is observed even when $f_0 > f_{0F_2}$ if $f_{uh} < f_{0F_2}$ and the upper hybrid waves can be excited in the ionosphere. In this case the QPAO may appear with delay time of a few seconds. The generation of the QPAO is not observed when $f_{uh} > f_{0F_2}$. It is important to note that the QPAO generation is also observed when the X-mode probing wave reflects below the upper hybrid resonance level for the pump wave.

- The QPAO are most pronounced during a few seconds — ten seconds of pumping. As a rule, their amplitude decrease with development the X-mode anomalous attenuation and appearance of strong X-wave amplitude fluctuations. The latter indicates the ALSI growth.

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- For high power heating under night conditions and when $f_x \simeq f_0 + 0.7$ MHz the frequency of the beats has the highest magnitude $F_b \simeq 3$ Hz practically after the pump switch on and during the X-mode anomalous attenuation development it is lowered by approximately two times or more. In day time or at low pump power ($P \leq 20$ MW ERP) the amplitude and frequency of the beats may increase during a few seconds — tens seconds up to the largest magnitudes, after that they decrease again. The frequency F_b lowers abruptly (for instance, from $2 - 3$ Hz to $0.5 - 0.3$ Hz) when ionospheric conditions are changed from overdense to underdense heating but when $f_{uh} < f_{0F_2}$ yet.

- After long-time heating under the condition when $f_x \simeq f_0 + 0.7$ MHz, the QPAO (if they can be distinguished on the background of the artificial fluctuations of the probing wave amplitude) are observed, as a rule, not longer than $1 - 2$ s. A process of their relaxation usually are clearly seen for the short-time pumping when the ALSI are not developed yet. In this case their relaxation time is $\sim 350 - 500$ ms.

In spite of a large body of data available, up to now no adequate theoretical interpretation of this phenomenon has been presented. Clarification of QPAO nature is very important for understanding artificial ionospheric turbulence features as a whole because such usually observed large-scale variations of plasma characteristics have conclusively to exert a strong influence on other wave-plasma interactions.

In summary, the results presented in this report represent our efforts aimed at studying the coupling between powerful electromagnetic waves and magnetized plasmas. Numerous phenomena revealed in the experimental and theoretical investigations have shown that considerable progress has been made toward understanding the nature and causes of the artificial ionospheric turbulence generation and consequently the ALSI features. This work will not only be important within the framework of ionospheric modification, but for plasma physics in general and its application to the natural ionosphere. This field of plasma physics remains open to further experimental and theoretical work, because many phenomena are not yet fully investigated and explained.

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I. Description of the experiment

Experimental study in the framework of the Contract was performed at the Sura heating facility on August 17 – 22, 1998. In the measurements we used the following tools:

a) SEE *measurements to study evolution of small-scale irregularities (striations), which are* responsible for transferring of the pump wave energy to plasma as result of scattering of O-mode powerful waves in upper-hybrid plasma waves (the anomalous absorption effect);

b) chirp-sounding measurements to study features of 100-1000 m scale length irregularities which are responsible for formation of the F_{spread};

c) sounding of the HF disturbed ionospheric volume by means of HF extra-ordinary probing waves to study features of 50-100 m scale length irregularities responsible for scattering of X-mode waves, which is associated with so-called the X-mode anomalous attenuation;

d) scintillation measurements using VHF signals of satellite beacons at $f \simeq 250$ MHz to study features of $50 - 1000$-m irregularities;

e) field-aligned scattering measurements using UTR-2 radio telescope to study features of dekameter striations;

f) HF sounding of the disturbed volume to study its space structure.

Duration of the campaign was 30 hours for heating. Experiments were conducted using O-mode pump wave only under both day and night time conditions. In the measurements the pump frequency was both below and above the F_2 critical frequency, far from gyroresonance regions and close to the 4th gyroharmonic frequency; a square amplitude modulation of the HF pump at different modulation frequencies was also used. The measurements have been aimed at understanding (1) physical processes, which dictate development of artificial large-scale irregularities (ALSI), (2) the role of the striations in ALSI generation, and (3) an influence of natural conditions on ALSI features.

II. Experimental results obtained during the heating campaign

1. We have found that generation of strong ALSI, which manifests itself in F_{spread} on ionograms, scintillations of satellite signals passed through the disturbed volume, and fluctuations of amplitude of X-mode probing wave sounding the disturbed volume, is observed only for overdense heating (when $f_{HF} \leq f_{oF_2}$) and appear and disappear simultaneously with the DM (downshifted maximum) in SEE spectra, generation of which is determined by the striations. It gives grounds to consider that not the self-focusing instability but transferring of pump energy due to thermal parametric instability development plays a key role in the ALSI generation when O-mode wave is used for pumping. This statement have been also confirmed by suppression of the ALSI generation in a frequency range near the 4th gyroharmonic frequency similarly to well studied suppression of the DM generation in gyroresonance frequency ranges.

2. Under different ionospheric conditions the typical growth and decay times have been found for irregularities with scale length in transverse to the geomagnetic field line direction from $\sim 3 - 5$ m to several kilometers.

3. It has been found that employing a square amplitude modulation of the HF pump at different modulation frequencies provides a way to control over ALSI spatial spectrum.

probing waves has been observed. The beats appear almost simultaneously with switch-on of the pump wave (within not more than a few hundred milliseconds after start of pumping), its relaxation time is not more than a few seconds but very often it is less than one second. Its typical frequency is of $\sim 1 - 3$ Hz. The beats are more pronounced at an initial stage (during a few tens of seconds) of pumping when the X-mode anomalous attenuation is not developed yet. There is reasons to believe that the beats are a result of Doppler beating of two waves one of them is the sky wave, observed also in the pause of pumping, and the second one is a new sky wave produced by heating, nature of which is unknown yet.

III. Research plans

1. To analyze spectra of scintillations for satellite and X-mode sounding measurements using FFT technique.

2. To prepare for publication experimental data regarding to the following points:

a) typical growth/decay times for artificial irregularities of different scale lengths;

b) results of over- and underdense heating;

c) gyroharmonic effects;

d) effects connected with a square amplitude modulation of the HF pump at different modulation frequencies;

e) fine structure of the disturbed volume.

3. To study nature of the beats.

4. To elaborate methods of control over ALSI properties.

5. To draw up the final report.

L. M. Erukhimov (P.I.), E. N. Myasnikov, V. L. Frolov, V. V. Chugurin, A. V. Rakhlin,
E. N. Sergeev

INTRODUCTION

According to the work program, at the first stage of the contract we deal with the following subjects:

1) peculiarities of generation and decay of the artificial large-scale ($l_\perp \geq 50 - 100$ m) turbulence (ALST) HF-induced in the ionosphere;

2) relationship between generation of the ALST and ASST (small-scale turbulence, $l_\perp < 50$ m);

3) elaboration of new diagnostic methods for investigation of ALST spatial coherent structures and in ASST monitoring.

To study different parts of a turbulence spectrum, it is needed different kinds of measurements (phase and amplitude scintillations of probing waves sounding the disturbed volume, field-aligned scattering measurements in a wide frequency range, and others), which have to be made simultaneously or under similar ionospheric conditions. An other way, we can use some averaged experimental data obtained during many years of artificial turbulence investigation [1-6]. During last years we have studied also a opportunity to obtain more full information about ALST and ASST characteristics using as few investigation techniques and receiving sites as possible.

Working in the field of the artificial ionospheric turbulence investigation many years (since 1973), we have obtained a lot of principal results concerning ALST and ASST features by performance experiments at the Sura, Zimenki and Gissar heating facilities. We have also elaborated numerous methods for diagnostics of the artificial ionospheric turbulence for its different scale length regions.

In March and September 1996 we conducted experiments at different pump frequencies both far and close to an electron cyclotron harmonic devoted, first of all, to investigation of new opportunities for ASST and ALST diagnostics using stimulated electromagnetic emission (SEE) technique. In June 1996 we carried out another experiment for investigation of features of large-scale irregularities responsible for the F_{spread} phenomena. Using SEE and anomalous absorption measurements we studied also influence of the large-scale irregularities on generation of the small-scale irregularities (striations). During autumn of 1996 we also performed a preliminary experiment devoted to creation an artificial ionospheric lens due to a decrease of the recombination constant in the ionosphere with an increase in the electron temperature.

In last years we have systematized theoretical and experimental results concerning opportunities to control ALST features to be focused on preparation of future experiments, which are planned to start in September 1997.

Some results have been published in 1996, 1997 years. Others are now in preparation for the publication.

Below a quick view of obtained results is presented for a case when O-mode HF waves are used for pumping.

AN EMPIRICAL MODEL OF SPECTRAL CHARACTERISTICS OF THE ARTIFICIAL IONOSPHERIC TURBULENCE (AIT)

We start consideration of AIT features with a model of its spatial spectrum. This model have been developed on the basis of long-term observations, including scintillation measurements (SM), field-aligned scattering (FAS) measurements, measurements of the anomalous absorption (AA) of both the pump wave and low-power probing waves, and SEE measurements. The experiments are conducted at the Sura facility since 1982. If the FAS, SEE, and AA observations are employed to find AIT spectral characteristics in its small-scale region (for $l_\perp < 50$ m), the ALST spectral characteristics are studied using phase and amplitude scintillations of signals transmitted by orbital and geostationary satellite beacons.

It has been found that the outer scale $L_{0\perp}$ of the AIT in the north-south direction extends up to 100–150 km and is defined by the Sura facility antenna array beam. The phase scintillation spectra for $(0.5 - 1)$km $\leq l_\perp \leq L_{0\perp}$ have a power-law form $F_\varphi(k_\perp) \propto k_\perp^{-n}$ ($k_\perp = 2\pi l_\perp^{-1}$) with the power index $n = 3 - 4.5$. In the two dimensional (2D) approximation for the turbulence a power index p for a spectrum of electron density fluctuations ($F_N(k_\perp) \propto k_\perp^{-p}$) equals to the phase power index for the spectrum of the phase fluctuations: $p = n$. In our measurements $p \simeq 3 - 4.5$.

For the cross-field irregularity scale length $l_\perp \sim 30$ km the field-aligned scale length ($l_{0\parallel}$) can be as large as 200–300 km. The field-aligned inner scale (FAIS) $l_\parallel$, derived from the dependence of scintillation character on the angle between the line of sight to a satellite and the geomagnetic field line, is of about of 10 km (for $l_\perp \simeq 1$ km). For $0.1 \leq l_\perp \leq 0.5$ km the index n, derived from the amplitude and phase scintillations, is of 1.5–2. Because for the 2D spectra $n = p$, we can expect that a range $0.1 \leq l_\perp \leq 0.5$ km there is a flattening of the ALST spectra. In this connection it should be noted that for irregularities with $l_\perp \simeq 0.1 - 0.2$ km the FAIS $l_\parallel$ is of ~ 1 km (or may be a few times larger). Notice also that the maximum in the amplitude scintillation spectra at $0.1 \leq l_\perp \leq 0.5$ km was revealed in the first observations of the HF-induced scintillations over the Boulder and Zimenki heating facilities.

Another weak maximum has been distinguished in the AIT spectrum at $l_\perp \simeq \lambda_0$, where $\lambda_0 \simeq 30 - 50$ m is the HF pump wave length. For $l_\perp < \lambda_0$ a value of the spectral index p varies from $p \simeq 1 - 2$ for $l_\perp \simeq 10 - 30$ m through $p = 3$ for $l_\perp \simeq 3 - 10$ m to $p \simeq 4 - 5$ for $l_\perp \simeq 1 - 3$ m. These results relate to steady state features of the small-scale turbulence and have been obtained at $P_{eff} \simeq 20$ MW ERP.

The FAIS for $l_\perp \simeq 2 - 3$ m is not larger than the vertical size Δz of the region with such a turbulence, which is of $\sim 2 - 3$ km in accordance with available experimental data. However, short path backscatter measurements, performed in Gorky in 80th years, have shown that HF-induced irregularities with $l_\perp \simeq 30 - 100$ m can expand down with the velocity up to 1–2 km/s occupying an altitude region of ~ 100 km below the pump wave reflection level, which may be considered as a region of turbulence sources. Earlier, for the irregularities with $l_\perp \simeq 1$ km we have obtained the turbulence expansion from the pump wave reflection level to higher altitudes with the longitudinal velocity $v_z \geq 1$ km/s.

A SCENARIO OF AN INITIAL STAGE OF ARTIFICIAL TURBULENCE DEVELOPMENT

Temporal evolution of the ASST is determined by such key parameters as pump power, pump frequency and a schedule of pumping. The level of natural or residual artificial turbulence as well as the diurnal and other variations of the ionospheric parameters are also very

important. Notice that the AIT generation is observed only if the effective pump power P_{eff} exceeds threshold power $P_{th} \simeq 0.5$ MW approximately corresponding to threshold power for the thermal parametric instability (TPI) [2].

When the pump power exceeds a few MW (of about of 2 MW ERP at 6 MHz) an abrupt decrease of pump wave amplitude by $6 - 12$ dB is observed within a few milliseconds after the pump turn on. This phenomenon is connected most probably with the parametric decay instability (PDI), which is developed in a vicinity of the pump wave reflection level. It is named as the striction self-action of the pump wave.

If the pump power is more than $1.5 - 2$ times higher than the PDI threshold, at the second stage of pumping, which lasts from ~ 0.05 s to $\sim 0.5 - 3$ s, rapid quasi-periodic oscillations with increasing from ~ 0.05 s to ~ 1 s period appear on reflected from the ionosphere the pump wave signal. Growth of pump wave average amplitude at this stage is also observed.

At the third stage of the pump wave – ionospheric plasmas interaction (during 0.5–10 s after pump wave turn on) small-scale field-aligned irregularities (striations) with the $l_\perp$ from $1 - 2$ m (and may be even from smaller $l_\perp$) to tens of meters are developed.

For $0.5 \leq P_{eff} \leq 5$ MW ERP a gradual increase in intensity of artificial field-aligned scattering (AFAS) signals is observed with the growth time $\tau_{gr} \simeq 3 - 30$ s, the value of which depends on the effective radiated power as $\tau_{gr} \propto P_{eff}^{-1}$. However, if $P_{eff} \geq 5$ MW ERP, the very rapid increase in AFAS intensity for $l_\perp \simeq 3$ m occurs with the typical growth time $\tau_{gr} \simeq 0.2-1$ s ($\tau_{gr} \simeq 0.2$ s for $P_{eff} = 100$ MW ERP), which increases with ASST scale-length growth showing dependence $\tau_{gr} \propto l_\perp^2$. Notice that the ASST intensity growth begins only after a delay time t_{del} lasting a few hundred milliseconds being in direct proportion on $l_\perp$ and in inverse proportion on P_{eff}. For $P_{eff} > 10$ MW ERP the 3-m irregularities show a maximum of their intensity within a few seconds of pumping. Such a maximum is never observed for ASST with $l_\perp \geq 7$ m.

For $P_{eff} \geq 5$ MW ERP the fast stage of an anomalous absorption (AA) of both the pump wave and diagnostic waves at frequencies close to pump wave frequency can be distinguish within $\sim 0.3 - 0.5$ s after start of pumping. It has been found that the fast stage of AA development is determined by growth of the 3-m striations while dekameter striations control the slower stage of the AA development.

Generation of the most intensive ASST with $l_\perp \leq 3$m during a few seconds of pumping explains the effect of wave cross-modulation in the ionospheric F-region when the O-mode pump wave, square modulated in its amplitude, results in amplitude modulation of diagnostic waves both O and X polarization in a wide frequency range of about of ± 200 kHz around the pump wave frequency. The effect of the cross-modulation almost disappears with the AA development.

The relationship of the ASST, the different stages of the AA development, and generation of different SEE components gives an opportunity for ASST diagnostics employing different kind of observations in one point placed nearly the heating facility. It is more convenient to carry out such measurements than the AFAS ones.

Our study of ASST temporal evolution for different striation scale length $l_\perp$, derived from AFAS measurements for both long and short time of heating, has shown occurrence of inverse type of the ASST spectrum (when $p < 0$) at the initial stage of pumping. This inversion disappears within a few seconds after pump wave turn on when the slow stage of AA development is observed. It has been found that the development of the turbulence with $l_\perp \geq 10$ m suppresses the generation of the ASST with $l_\perp \sim 2 - 3$ m.

In this connection it is interesting to note that behavior of the ASST, when short pulse

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pumping with $\tau_p \simeq 0.05-0.3$ s is used, shows growth of the turbulence intensity already after pump wave switch off. Then the ASST intensity can strongly decrease for a short period to be growing again and only after that a relaxation stage occurs. For $\tau_p \sim 0.1-0.3$ s this second increase of the ASST intensity is observed within a delay time of $\sim 1-3$ s after the pump wave switch off showing growth its value from pulse to pulse of pumping even if these pulses are separated one from another by a pause $T_p \simeq 100\tau_p$. If the ASST is created by means of a sequence of short pumping pulses with their duration τ_p and an interpulse period $T_p \gg \tau_p$ (up to $T_p \simeq 100\tau_p$) it is observed very interesting manifestation of the second stage of the turbulence development: for each next pulse the second maximum of the scattered signal is more pronounced and has longer decay time. The averaged pattern of the ASST behavior shows that the position of the maximum of the turbulence intensity depends on relation between τ_p and T_p increasing with both a decrease of T_p and growth of τ_p.

One can believe that these data show an energy transport from small-scale to larger scale at the initial stage of pumping, when the inverse type of the AIT spectrum is observed. At the steady state the AIT spectrum with $p > 0$ is established, and the energy of turbulence goes back from disturbances with larger scale lengths to smaller ones where the energy dissipates.

DECAY OF ARTIFICIAL IONOSPHERIC TURBULENCE

Decay of the AIT HF-induced using long-time heating begins just after pump wave switch off and shows at first fast and then slower relaxation rates. At the first (fast) stage typical decay time τ_d as a rule has the following dependence of τ_d on $l_\perp$: $\tau_d \propto l_\perp^2$ for $l_\perp \leq l_\perp^*$ and $\tau_d \propto l_\perp^{0.5}$ for $l_\perp \geq l_\perp^*$, where $l_\perp^* \simeq 6-10$ m ($\tau_d \simeq 10-20$ s for the striation scale length $l_\perp^*$).

Assuming that for $l_\perp \leq l_\perp^*$ we deal with cross-field diffusion, where $\tau_d \simeq k_\perp^2 D_\perp$ and $k_\perp = 2\pi/l_\perp$, we can find the diffusion rate factor $D_\perp$: $D_\perp = \tau_d l_\perp^2/4\pi^2 \simeq 3 \cdot 10^2 - 10^3$ cm^2/s. This value is in well agreement with the cross-field electron ambipolar diffusion factor $D_{e\perp} = \kappa_B(T_e + T_i)\nu_e/m\omega_b^2$, where T_e and T_i are the electron and ion temperature, respectively, κ_B is Boltsman's constant, ν_e is the electron collisional frequency, and ω_b is the electron cyclotron frequency.

For scales $l_\perp \geq l_\perp^*$, taking into account slow dependence of τ_d on $l_\perp$, one can be assumed that we deal here with the field-aligned diffusion. Going on this line we can obtain that $D = D_\parallel \sim l_\parallel^2/4\tau_d \simeq (1-5) \cdot 10^9$ cm^2/s. This value corresponds to the field-aligned ion rate of diffusion $D_{i\parallel} = \kappa_B(T_e + T_i)/M\nu_{in}$, where M is the ion mass and ν_{in} is the collisional frequency of ions with neutrals. Notice that in accordance with this formula our observations show a decrease of τ_d with increasing the heated region height z in the ionosphere due to dependence of ν_{in} on z.

The longer AIT decay time at the following stage of the ASST relaxation is connected with supporting of the ASST by the ALST (i.e. by the turbulence having larger scales).

Peculiarities of the ASST decay after short pulse pumping have been considered in the previous section and, like the case of the long-time pumping, has also two (sometimes three) stages.

It is obviously now, that short interrupting in the pumping has to kill, first of all, very small-scale irregularities. This means that the study an aftereffect of the short interrupting in pumping has to help us to find an influence of the small-scale irregularities on generation of the ALST. The experiments performed by L. Erukhimov and E. Sergeev in 1986 at the Gissar facility (Dushanbe) have shown an influence of such an interruption on the AA growth-time.

At night time the AIT demonstrates an ability to be easier excited after start of pumping and to be longer time after pump wave switch off in comparison with daytime conditions. It is interesting to note that at night the value of τ_d is about two times longer than in day and does not almost depend on $l_\perp$ for $l_\perp \leq l_\perp^* \simeq 7$ m while it remains in proportional to $l_\perp^2$ for $l_\perp \simeq 7 - 14$ m. At night the AIT for $l_\perp > 0.1 - 1$ km manifests itself in the F_{spread} and being created artificially can transform sometimes to the natural F_{spread}.

Moreover, our experiments in 1986 at the Gissar facility have demonstrated an ability to support a non-saturated artificial F_{spread} by means of very short pulse pumping. This can also add believing that the small-scale AIT can play rather important role in the ALST generation.

In the whole, investigations of sources of the artificial turbulence at night is very important not only for understanding the coupling between the ALST and ASST but for modeling of diurnal variations of natural turbulence features in the middle latitudinal ionosphere as well.

ON SPATIAL DISTRIBUTION OF ARTIFICIAL IONOSPHERIC TURBULENCE

The measurements performed by means of the Ukraine radio telescope UTR-2 have shown that often the ASST has spatially located structures. Our measurements of the artificial F_{spread} demonstrate that this phenomenon is easier created if the natural gravity waves are registered by ionosond.

In the frame of the contract in June 1996 we also observed artificial F_{spread} at two stations: in Vasil'sursk (near the Sura facility) and in Zimenki located about 120 km to the west from Vasil'sursk. It has been stated that the ALST, which have to be responsible for the F_{spread}, after delay time approximately corresponding to drift transportation of irregularities appears over Zimenky. This is a hint that either the kilometer scale length turbulence supports well by larger scale length irregularities or the F_{spread} is induced by 10–50 km irregularities directly. To verify the role of the AIT with different sizes for F_{spread} generation we are also going to study the connection between F_{spread} development (decay) and behavior of the anomalous absorption. The preliminary results are in well agreement with an assumption that artificial "waveguids" can form the retarded short pulse signals reflected from the ionosphere.

ON OPPORTUNITY TO CONTROL THE ALST AND ASST PARAMETERS

In 1977 we proposed a method of controlling AIT parameters, just after that we proved experimentally the opportunity to depress the AIT intensity by means of periodic modification of the ionosphere. Later, in Dushanbe (see, e.g., [6]), we used double quasi-periodic heating schedule (when during a limited-in-time heating period the pump wave is radiated in a pulse mode) for generation of the ALST with scale lengths comparable with the beam pattern of the heater. A complex temporal heating schedule have been also used for selection of the ALST responsible for both HF-induced scintillations from satellite beacons and F_{spread} [3]. Another way is to use frequencies for pumping just below an electron cyclotron harmonic where the plasma waves (as well as the ASST) are suppressed [4] and pump energy can effectively absorb in the pump wave reflection layer to produce the ALST. Notice, that the empirical methods used are in agreement with the theoretical methods describing the control for parameters of the non-linear media.

The theoretical method of the control for ALST parameters using excitation of spatial-temporal coherent structures in the heating experiments is based on representative of the ionosphere turbulence as nonlinear dissipative dynamic system, NDDS. From this point of view we determine the terms of control here as small perturbation of parameters of the controlling media [7, 8]. Three main parameters p_α, $\alpha = 1, 2, 3$ we take into account in the proposed experiment. p_1 is a parameter, which keeps the ALST at a quasi-stable level, p_2 is a driving parameter, we change it during experiment in accordance with a feedback replay from the ionosphere. Obviously both parameters in the real task depend on "Sura" facility transmitted power. We have shown [11] that it is possible the effective control of the NDDS even if the power of the second signal is essentially less than of the first one. In that case the target time (time which is needed to change the signal's level from one to another) is equal of turbulence typical time scale. p_3 is a proper parameter controlling of the ALST.

As have been proposed before, we willing to use different methods for diagnostics of the AIT including stimulated electromagnetic emission. In order to prepare to the experiment we work on theoretical background of the control problem. We test the proposed method by system of the complex Ginzburg-Landay equation, which we use as a model of the ALST:

$$\frac{dw_j}{dt} = w_j - (1 + i\beta) \mid w_j \mid^2 w_j + e(1 - ic)(w_{j+1} - 2w_j + w_{j-1}), \quad j = \overline{1, M} \qquad (1)$$

with periodic conditions $w_0 = w_M$, $w_{M+1} = w_1$. We offer a new method [5], which differs from the OGY one [7] in that the trajectory tends directly to a desired state (in the OGY method it tends to the stable manifold at this state). The method is based on discrete and continuous maximum principles and optimizes the mean time needed to achieve the control even at large distances from the desired state. It have been shown [12] that possible to control unstable coherent structures by small perturbation of control parameter.

Notice that the method we proposed (and software prepared for such an experiment) here possible to use not only for the model equation but in real experiments because the control scheme does not use any a priori information about the system.

For diagnostics the coherent spatial-temporal structures in the ALST we use the method named Ω-dimension (or Spectral density of fractal dimension) [10]. From this method we can estimate the number of nonlinear structures in a bounded region of the space. The method is stable enough relatively to noise and might be used for experimental goals [9]. At the present time we are working on adaptation of both methods to Labview software which we willing to use during experiments.

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